

ON THE ENERGY FLUXES OF LOW-ENERGY  
PROTONS AND POSITIVE IONS  
IN THE EARTH'S INNER RADIATION ZONE\*

by

L. A. Frank and R. L. Swisher

Department of Physics and Astronomy  
University of Iowa  
Iowa City, Iowa

June, 1967

\*Research supported in part by the National Aeronautics and Space Administration under Grant Nsg-233-62 and Contract NAS5-2054 and by the Office of Naval Research under Contract Nonr-1509(06).

Distribution of this document is unlimited.

A large energy flux, exceeding  $50 \text{ ergs}(\text{cm}^2\text{-sec-sr})^{-1}$ , of low-energy protons or ions within the energy range  $\sim 0.5 \text{ keV}$  to  $1 \text{ MeV}$  at low altitudes in the earth's inner radiation zone was reported by Freeman [1962] via analysis of the responses of CdS crystals borne on the earth-satellite Injun 1. To our knowledge, these early results have neither been corroborated nor contested with further in situ measurements to the present date. Indeed, this large energy flux is remarkable as there exists no obvious energy source to maintain these positive ion fluxes against the taxation of heavy losses due to charge-exchange with the relatively high densities of ambient neutral and charged constituents of the terrestrial exosphere at these low altitudes. For example, an order-of-magnitude estimate of the energy source required to maintain these energy fluxes of low-energy ions, assuming charge-exchange as the principal loss mechanism, provides a basis of comparison of this source with the average energy precipitated into the earth's upper atmosphere in the auroral zones. If we assume that the energy fluxes reported by Freeman are predominantly  $\sim 1 \text{ keV}$  protons (energy densities  $\sim 2 \times 10^{-6} \text{ erg}(\text{cm})^{-3}$ ) and the spatial distribution is confined between shells  $L = 1.25$  to  $L = 1.70$  and a spherical surface  $\sim 1000 \text{ km}$  altitude above the earth's surface ( $\sim 10^{27} \text{ cm}^3$ ) then the total energy of these low-energy protons is  $\sim 2 \times 10^{21} \text{ ergs}$  (see also Figure 1 which

includes a summary of Freeman's [1962] observations). The charge-exchange lifetimes of  $\sim 1$  keV protons at these altitudes, without consideration of comparable Coulomb scattering lifetimes, is generously  $\sim 2 \times 10^3$  seconds [Liemohn, 1961]. Hence our gross order-of-magnitude estimate of the power required to maintain this reservoir of low-energy protons is  $\sim (2 \times 10^{21} \text{ ergs}) (2 \times 10^3 \text{ seconds})^{-1} = 10^{18} \text{ ergs}(\text{sec})^{-1}$ , a source strength which is comparable to that required for the average particle precipitation into the auroral regions [Frank and Van Allen, 1964; O'Brien, 1964].

Toward obtaining a more comprehensive study of these large energy fluxes of positive ions we have conducted an initial survey of measurements of the differential energy spectrums of positive ions ( $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$ ) in the inner radiation zone with an array of sensitive electrostatic analyzers borne on the earth satellite OGO 3 (launch date, 7 June 1966; initial apogee and perigee, 128,500 km and 6,700 km geocentric radial distances; inclination,  $31^\circ$ ) [Frank, 1967a, 1967b, 1967c]. Typical responses of this instrumentation during traverses of the spacecraft through the inner radiation zone have been previously given by Frank [1967b]. Of principal interest is the observation that the positive-ion electrostatic analyzers in the energy range  $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$  yield counting rates which are unmodulated by the variations in analyzer-plate voltages and are attributable to high-energy protons and electrons deep within the inner radiation zone,  $L \leq 1.6$ . We have examined data obtained during several perigee passes of OGO 3 in search of a large

positive ion flux and have summarized the upper limits for energy fluxes of positive ions ( $Q \leq 2$ ) at ten locations in the inner zone in Figure 1. These upper limits have been generously calculated by assuming that the responses of the electrostatic analyzers are wholly due to a low-energy positive ion flux. No evidence for the large energy flux in the inner radiation zone as reported by Freeman has been found with the present measurements of positive ions within the energy range  $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$ . In fact a cursory examination of the summary of Injun 1 observations [Freeman, 1962] and of the present OGO 3 measurements in a B-L coordinate system (Figure 1) emphasizes that the energy fluxes reported by Freeman exceed the upper limits provided by the electrostatic analyzer array borne on OGO 3 by factors  $\sim 10$  to 100. It should be noted by the reader that all measurements presented here in Figure 1 and in tabular form were obtained at local pitch angle  $\alpha = 90^\circ$ . Several upper limits for energy fluxes nearer to the magnetic equatorial plane than the Injun 1 observations above are given in Table I. At these lower magnetic latitudes there is still no signature of a large positive-ion energy flux within the energy range  $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$ . Upper limits for negative-ion ( $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$ ) energy fluxes as derived from the responses of companion electron electrostatic analyzers are within a factor  $\sim 2$  equal to the simultaneously measured upper limits for positive-ion energy fluxes reported here.

TABLE I

UPPER LIMITS FOR ENERGY FLUXES  
OF LOW-ENERGY POSITIVE IONS IN  
THE EARTH'S INNER RADIATION ZONE

OGO 3

$100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$

June-July, 1966

L, earth radii	B, gauss	Energy Flux*(upper limit), $\text{erg}(\text{cm}^2\text{-sec-sr})^{-1}$
1.34	0.150	2.0
1.35	0.128	4.4
1.54	0.109	2.2
1.59	0.117	2.6

\*At local pitch angle  $\alpha = 90^\circ$

Since the Injun 1 observations with CdS crystals cover the energy range  $\sim 500$  eV to  $\sim 1$  MeV, there remains the possibility that the energy flux is shared predominantly by positive ions in the energy range exceeding that of the OGO 3 electrostatic analyzer, or  $\sim 50$  keV to 1 MeV. In order to investigate this possibility we have analyzed unpublished Injun 4 (launch, 21 November 1964; initial apogee and perigee altitudes, 2502 km and 527 km; inclination,  $81^\circ$ ) observations of proton  $E > 30$  keV energy fluxes (d. c. scintillator, courtesy of J. D. Craven) and of proton  $0.5 \leq E \leq 4.2$  MeV intensities (solid-state detector, courtesy of S. M. Krimigis and T. A. Armstrong) during January 1965 in order to provide the upper limits for these proton energy fluxes as summarized in Table II. Again these energy fluxes are less than the Injun 1 values by factors  $\sim 10$  to 100.

It is possible that (1) the large energy fluxes of positive ions are present only near local midnight where all Injun 1 measurements were obtained [Freeman, 1962] and hence that the OGO 3 observations during local day presented here simply imply that these low-energy positive ions are confined to a restricted local-time range centered near local midnight (the Injun 4 measurements are also near local midnight) or (2) these low-energy positive ions have disappeared via an occasional loss mechanism over the period extending from mid-1961 to 1966. However, on the basis of our present findings of upper limits for these energy fluxes which are less by factors of 10 to 100 when compared to the energy fluxes reported by Freeman over a large region of the inner zone

we conclude that most probably energy fluxes of positive ions ( $500 \text{ eV} \lesssim E \lesssim 1 \text{ MeV}$ ),  $\sim 50 \text{ ergs (cm}^2\text{-sec-sr)}^{-1}$ , are not a feature of the inner radiation zone.

TABLE II

SEVERAL UPPER LIMITS FOR ENERGY FLUXES  
OF PROTONS IN THE EARTH'S INNER RADIATION ZONE

INJUN 4  
January 1965

L, earth radii	B, gauss	Energy Flux*(upper limits), erg(cm <sup>2</sup> -sec-sr) <sup>-1</sup>	
		protons <sup>+</sup> E > 30 keV	protons <sup>±</sup> 0.5 ≤ E ≤ 4.2 MeV
1.35	0.151	2.5	5 × 10 <sup>-4</sup>
1.49	0.182	0.2	6 × 10 <sup>-3</sup>
1.50	0.167	1.5	- -
1.51	0.170	1.0	2.6 × 10 <sup>-4</sup>
1.55	0.179	0.7	1.4 × 10 <sup>-2</sup>

\*At local pitch angle  $\alpha = 90^\circ$

+Courtesy of J. D. Craven

±Courtesy of S. M. Krimigis and T. A. Armstrong

Acknowledgements

The author is indebted to Dr. J. A. Van Allen for his support throughout the various phases of this research. This research was supported in part by the National Aeronautics and Space Administration under Grant NsG-233-62 and Contract NAS5-2054 and by the Office of Naval Research under Contract Nonr-1509(06).

References

- Frank, L. A., Initial observations of low-energy electrons in the earth's magnetosphere with OGO 3, J. Geophys. Res., 72, 185-195, 1967a.
- Frank, L. A., Several observations of low-energy protons and electrons in the earth's magnetosphere with OGO 3, J. Geophys. Res., 72, 1905-1916, 1967b.
- Frank, L. A., On the extraterrestrial ring current during geomagnetic storms, J. Geophys. Res., (to be published), 1967c.
- Frank, L. A. and J. A. Van Allen, A survey of magnetospheric boundary phenomena, Research in Geophysics, Vol. 1: Sun, Upper Atmosphere, and Space, Chapter 7, pp. 161-187, ed. by Hugh Odishaw, M.I.T. Press, 1964.
- Freeman, John W., Detection of an intense flux of low-energy protons or ions trapped in the inner radiation zone, J. Geophys. Res., 67, 921-928, 1962.
- Liemohn, H., The lifetime of radiation belt protons with energies between 1 keV and 1 MeV, J. Geophys. Res., 66, 3593-3595, 1961.
- O'Brien, B. J., High-latitude geophysical studies with satellite Injun 3. 3. Precipitation of electrons into the atmosphere, J. Geophys. Res., 69, 13-43, 1964.

Figure Captions

Figure 1. Comparison of Injun 1 observations of large energy fluxes of protons or positive ions ( $500 \text{ eV} \lesssim E \lesssim 1 \text{ MeV}$ ) [Freeman, 1962] and OGO 3 measurements of the upper limits for energy fluxes of positive ions ( $100 \text{ eV} \leq \frac{E}{Q} \leq 50 \text{ keV}$ ) in the earth's inner radiation zone.

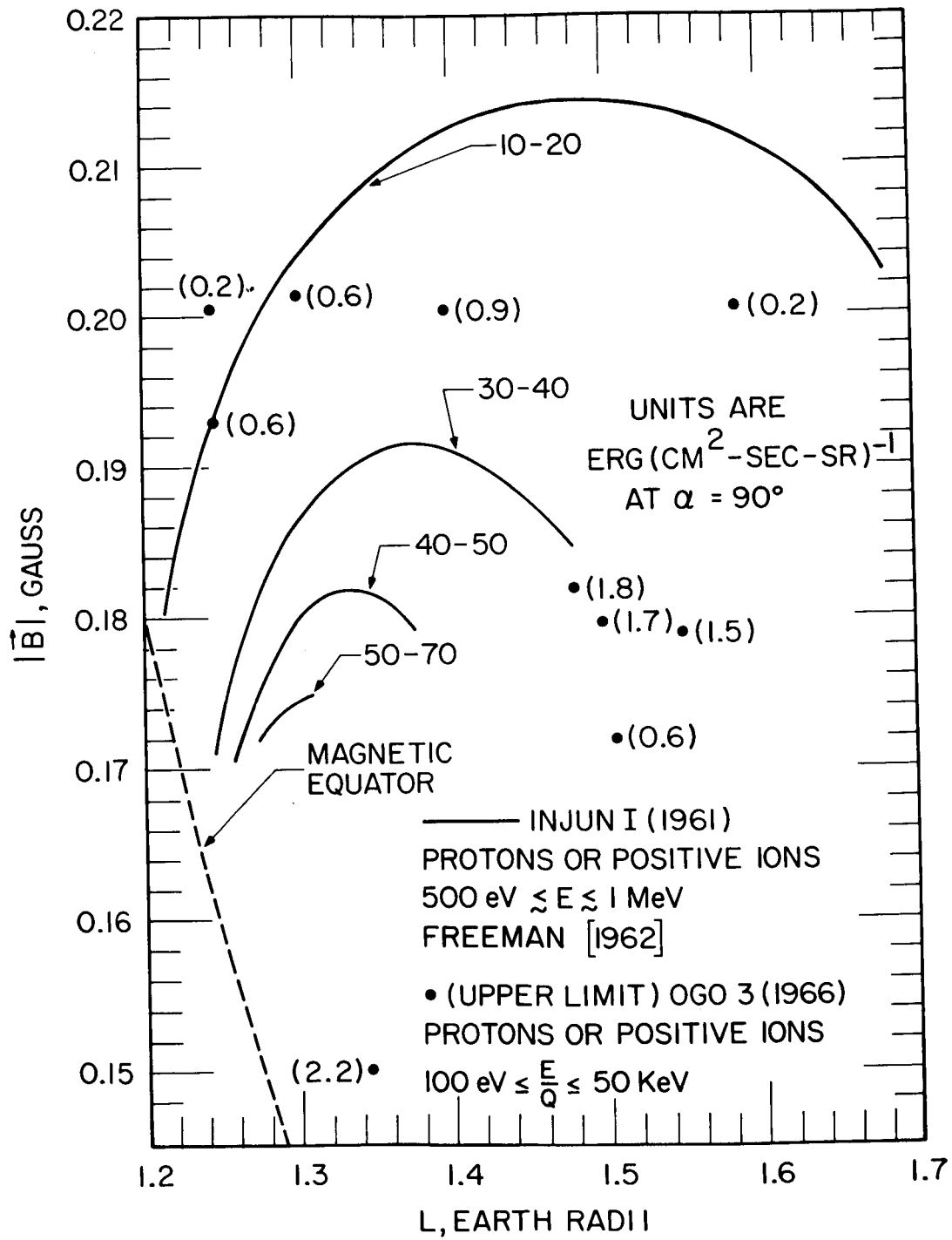


Figure 1

UNCLASSIFIED

Security Classification

## DOCUMENT CONTROL DATA - R&amp;D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) University of Iowa Department of Physics and Astronomy		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE On The Energy Fluxes Of Low-Energy Protons And Positive Ions In The Earth's Inner Radiation Zone			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Progress June 1967			
5. AUTHOR(S) (Last name, first name, initial) Frank, L. A. and R. L. Swisher			
6. REPORT DATE June 1967		7a. TOTAL NO. OF PAGES 12	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. Nonr-1509(06)		9a. ORIGINATOR'S REPORT NUMBER(S) U. of Iowa 67-33	
b. PROJECT NO.			
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research	

## 13. ABSTRACT

A search for the large energy fluxes of low-energy protons or positive ions ( $500 \text{ eV} \lesssim E \lesssim 1 \text{ MeV}$ ) in the earth's inner radiation zone as previously reported by Freeman via the analysis of the responses of CdS crystals borne on the earth-satellite Injun 1 is reported here utilizing recent measurements of energy fluxes of protons and positive ions within the energy range 100 eV to 4.2 MeV with earth-satellites OGO 3 and Injun 4. These recent measurements provide upper limits for these proton and positive-ion energy fluxes which are less by factors  $\sim 10$  to 100 when compared to the Injun 1 observations during 1961. The upper limits reported here strongly indicate that large energy fluxes of low-energy protons or positive ions,  $\sim 50 \text{ ergs (cm}^2\text{-sec-sr)}^{-1}$ , are not a feature of the inner radiation zone.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Inner Radiation Zone						
Magnetosphere						
Trapped Radiation						

## INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Distribution of this document is unlimited."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through \_\_\_\_\_."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through \_\_\_\_\_."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through \_\_\_\_\_."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.